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GEOPHYSICS.—*Geophysical research.*[1] ARTHUR L. DAY.

To write the history of the earth is a very different undertaking from writing the history of a people. In the latter case, a diligent seeker can usually find some ancient monastery where far-sighted historians of an earlier generation have collected the more important records which he requires, and placed them within reach of his hand. With the earth's history, which is the province of geology, it is another matter. The great globe has been millions of years in the making, and except for a mere fragment of its most recent history, it has had neither a historian nor an observer. Its formation has not only extended over an almost incomprehensible interval of time, but we have no parallel in our limited experience to help us to understand its complicated development, and no system of classification adequate to the task, even of grouping in an orderly way all the observed rock and mineral formations with reference to the forces which moulded them. And even if we could correctly interpret all the visible rock records, we are still quite helpless to comprehend all those earlier activities of the formation period, whose record is now obliterated.

To the student of the earth's history, therefore, the problem of gathering and ordering such a widely scattered and heterogeneous collection of effects and causes is one of somewhat overwhelming scope and complication. In the industrial world, a situation of this kind soon results in replacing individual effort with collective effort, in the organization of a system of a scope

[1] Presidential address delivered at the 700th meeting of the Philosophical Society of Washington, November 25, 1911.

more appropriate to the magnitude of the task. We are familiar with industrial organization and the wonderful progress in the development of American industries which has everywhere followed it. We are also familiar with organized geological surveys and the success which has attended them in geological and topographical classification. But the idea of organizing research to meet a scientific situation of extraordinary scope and complexity is still comparatively new. The very words science and research are still regarded as referring to something out of the ordinary, something to be withheld from the common gaze, to be kept hidden in a special niche, behind a mysterious curtain and served by priests of peculiar temperament and unpractical ideals. This is both disparaging to our good sense and prejudicial to the progress of knowledge. Scientific research is not a luxury; it is a fundamental necessity. It is not a European fad, but is the very essence of the tremendous technologic and industrial success of the last twenty years, in which we have shared.

Professor Nichols, of Cornell, as retiring president of the American Association for the Advancement of Science, put the case in this way "The main product of science (research) . . . is knowledge. Among its by-products are the technologic arts, including invention, engineering in all its branches, and modern industry." The idea of scientific research is therefore not less tangible than industrial development, or less practical; it is merely one step more fundamental; it is concerned with the discovery of principles and underlying relations rather than their application. This being true, research should profit as much, or even more, from efficient organization as industrial development has done.

Altho this conclusion is making its way but slowly in American science, in geological research, where material must be gathered from the utmost ends of the earth and even from within it, and where nearly every known branch of scientific activity finds some application, there is a peculiarly favorable opportunity for organized effort which is already coming to be recognized. "So long as geology remained a descriptive science," says President Van Hise of Wisconsin, "it had little need of chemistry and

physics; but the time has now come when geologists are not satisfied with mere description. They desire to interpret the phenomena they see in reference to their causes—in other words, under the principles of physics and chemistry. . . . . This involves coöperation between physicists, chemists and geologists."

In a general way, physics, chemistry and biology have already supplied working hypotheses which have been used by students of geology to help in the examination, classification and mapping of the most conspicuous features of the exposed portion of the earth. The geologist has gone abroad and has studied the distribution of land and water, the mountain ranges, the erosive action of ice and of surface water and the resulting sedimentary deposits, the distribution of volcanic activity and of its products, the igneous rocks; or more in detail he has studied the appearance of fossils in certain strata, and has inferred the sequence of geologic time. The distribution of particular minerals and of ore deposits has been carefully mapped. Regions which offer evidence of extraordinary upheaval thru the exercise of physical forces have been painstakingly examined, and so on thru the great range of geologic activity. In a word, the field has been given a thoro general examination, but the manifold problems which this examination has developed, altho early recognized, and often the subject of philosophical speculation and discussion, still await an opportunity for quantitative study. They are often problems for the laboratory and not for the field, problems for exact measurement rather than for inference, problems for the physicist and chemist rather than for the geologist. This is not a result of oversight, it is a stage in the development of the science, —first the location and classification of the material, then the laboratory study of why and how much.

Certain indications have led us to believe, for example, that the earth was once completely gaseous and in appearance much like our sun. Indeed, it possibly formed a part of the sun but thru some instability in the system became split off—a great gaseous ball which has cooled to its present condition. The cooling probably went on rapidly at first until a protecting crust formed about the ball, then more and more slowly, until now, when our

loss of heat by radiation into space is more than compensated by heat received from the sun. Obviously, the earliest portions of this history are and must remain dependent upon inference but the formation of a solid crust cannot advance far before portions of it become fixed in a form such that further disturbance does not destroy their identity. From this point on the history of the earth is a matter of record and can be interpreted if only we have sufficient knowledge of the mineral relations thru all the stages of their development.

It must have been a very turbulent sea, the molten surface of our earth upon which the rocky crust began to form. The first patches of crust were probably shattered over and over again by escaping gases and violent explosions of which our waning volcanic activity is but a feeble echo. If the earth was first gaseous, and the outer surface gradually condensed to a liquid, its outer portions at least must have been whirled and tumbled about sufficiently, even in a few thousand years (which is a very small interval in the formation of an earth), to mix its various ingredients pretty thoroly. It has accordingly been hard to see just how it came to separate into individual rocks of such widely different appearance and character. Of course the number of its ingredients was large. We have already discovered eighty or more different elementary substances in the earth, and there is an almost endless number of more or less stable compounds of these. The freezing of an earth is therefore different from the freezing of pure water, but the freezing of salt water offers a clue to the explanation of the way in which the earth solidified as we find it. When salt water freezes, the salt is practically all left behind. The ice contains much less salt and the remaining water relatively more salt than before freezing began. Applying this familiar observation to the supposed molten surface of the earth as it begins to solidify, we have a suggestion of order and reason in its separation into so many kinds of rocks.

Now, it happens that in the recent development of chemistry much attention has been given to the study of solutions of various kinds, and a great body of information has been gathered and classified of which our observation upon the freezing of salt water

is a simple type. Still more recently (quite lately in fact), it has occurred to many students of the earth that here lies not only the clue but perhaps the key to their great problem. If the individual components which are intimately mixed in solution separate wholly or partially in some regular way upon freezing—and nearly all the solutions which have been studied appear to show such segregation—we have a quantitative system which will probably prove adequate to solve the problem of rock formation, provided only that the experimental difficulties attending the study of molten rock and the complications imposed by the presence of so many component minerals, do not prove prohibitive. This is a very simple statement of the point of view which has led to the experimental study of rock formation in the laboratory as a natural sequence to statistical study in the field.

Geophysics therefore does not come as a new science, nor as a restricted subdivision of geology, like physiography or stratigraphy, but rather to introduce into the study of the earth an element of exactness, of quantitative relation. It may include physics or chemistry, biology or crystallography or physical chemistry, or all of these at need. The distinctive feature of geophysics is not its scope, which may well be left to the future, but its quantitative character. The Geophysical Laboratory of the Carnegie Institution at Washington has entered upon some of the investigations suggested by this long preliminary study of the earth,—the physical properties and conditions of formation of the rocks and minerals. The Department of Terrestrial Magnetism of the same institution has undertaken another,—the earth's magnetism; the German Geophysical Laboratory at Göttingen a third,—the earthquakes—and these will no doubt be followed by others.

The first effect of calling exact science into consultation upon geologic problems is to introduce a somewhat different viewpoint. It has been our habit to study the minerals and the rocks as we find them today, after many of the causes which have had a share in their evolution have ceased to be active,—after the fire has gone out. If we attempt to reconstruct in our minds the operations which enter into the formation of an igneous rock or

of a body of ore, we must infer them from present appearances and environment. The experimental geophysicist, on the other hand, confronting the same problem, says to himself: Can we not construct a miniature volcano in the laboratory, Can we not build a furnace in which an igneous rock can be formed under such conditions that we can observe its minutest change? He proposes to introduce temperature measuring devices and apparatus for the determination of pressure, to investigate the character of the surrounding atmosphere and the quantity of water vapor which may be present. He insists upon the chemical purity of every ingredient which goes into the furnace and guards it carefully against contamination. In these various ways he will undertake to ascertain the exact magnitude of all the causes, both physical and chemical, which have been at work in his miniature rock-producer, together with the physical characteristics of the product.

A very practical question now arises. Can he do all this successfully at the temperatures where the minerals form? We must press this question and insist upon a satisfactory answer, for it is by no means obvious that the relations which the physicist and chemist have established at the temperatures of everyday life—energy content, density, solubility, viscosity, dissociation—will continue to hold when substances are carried up to a white heat. The substances, too, are different from those with which the chemist and physicist have been generally familiar. Instead of simple metals, aqueous solutions, and readily soluble active salts, we encounter silicates and refractory oxides, inert in behavior and capable of existing together in mixtures of great complexity. We must therefore extend the range of our physics and our chemistry to a scope in some degree commensurate with the wide range of conditions which the earth in its development has passed thru. Let us follow for a little the actual progress of such an attempt.

The first step is to provide the necessary temperatures. Obviously, the common fire-clay crucible and the smelter's furnace with its brick lining, will not serve us, here, for all these are themselves mineral aggregates. The charge, furnace lining, and crucible would go down together in a fall as disastrous as Humpty

Dumpty's. But experiment has taught us that platinum crucibles, magnesia furnace tubes enclosing an electrically-heated helix of platinum wire, and electric temperature-measuring devices, provide a furnace in which nearly all of the important minerals can be successfully studied, which is not enough to melt zinc, silver, gold, copper, nickel or iron readily, and where any temperature up to 1600° Centigrade can be maintained perfectly constant if need be for several weeks. All these temperatures can be measured with no uncertainty greater than 5°. This equipment preserves the chemical purity of the mineral studied, and enables the temperature to be controlled and measured at every step of the experimental work. Or an iridium furnace tube and an iridium crucible can be substituted for platinum, the magnesia supports can still be used, and we have it in our power to go on to 2000° C., which is quite sufficient for all the more important minerals which we know.

The physicist has therefore found a suitable melting pot, and means of ascertaining what goes on within the pot; but he at once encounters another difficulty. Nature has provided us with relatively few minerals of high chemical purity. If a natural mineral is chosen for experiment, however typical it may be, several per cent of other minerals may be expected to be present with it, the effect of which is at present quite unknown. Now, the first axiom of the investigator in a new field who desires to undertake measurements which shall have a real value, is that the number of unknown quantities in his equations must not be greater than he can eliminate by his experimental processes; in other words, he must begin with conditions so simple that the relation between a particular effect and its cause can be absolutely established without leaving undetermined factors. Having solved the simple case, it is a straightforward matter to utilize this information to help solve a more complicated one. If we would therefore reduce the mineral relations to an exact science, which is our obvious purpose, it is necessary from the outset to prepare minerals of the highest purity and to establish their properties. Having obtained such a pure mineral type, it may be, and often is, in the power of the mineralogist and his microscope to determine,

by direct comparison with its natural prototype, the kind and amount of effect actually produced in the natural mineral by the one or more other minerals which it contains. We have therefore hardly started upon our investigation before the need of an organized system is demonstrated,—first comes the chemist, who prepares and analyzes the pure mineral for investigation; then the physicist, who provides and measures the conditions to which it is subjected; then the mineralogist, who establishes its optical properties in relation to the corresponding natural minerals.

Having prepared such a mineral, of high purity and of known crystalline character, we can ascertain its behavior at the temperatures which must have obtained during the various stages of earth formation. We can study the various crystal forms thru which it passes on heating and the temperature ranges within which these forms are stable; we can also melt it and measure the melting or solidifying temperature. Another mineral, prepared with the same care and studied in the same way, may afterward be added to the first, and the relation of these two determined. If they combine, heat is absorbed or released; and this quantity of heat can be measured, together with the exact temperature at which the absorption or release takes place. If the mixture results in the formation of one or more mineral compounds, we shall learn the conditions of formation, the temperature region within which the new forms are stable, and the changes which each undergoes with changes of pressure and temperature, as before. If the new forms show signs of instability, we can drop them into cold water or mercury so quickly that there will be no opportunity to return to initial stable forms, and thus obtain, for study with the microscope at our leisure, every individual phase of the process thru which the group of minerals has passed.

Without complicating the illustration further, it is obvious that we have it in our power to reproduce in detail the actual process of rock formation within the earth, and to substitute measurement where the geologist has been obliged to use inference; to tabulate the whole history of the formation of a mineral or group of minerals under every variety of condition which we may sup-

pose it to have passed thru in the earth, provided only we can reproduce that condition in the laboratory.

During the past quarter of a century, there has arisen in the middle ground between physics and chemistry a new science of physical chemistry, in the development of which generalizations of great value in the study of minerals have been established. As long ago as 1861 the distinguished German chemist, Bunsen, pointed out that the rocks must be considered to be solutions and must be studied as such; but inasmuch as comparatively little was known about solutions in those days, and the rocks at best appeared to be very complicated ones, no active steps in that direction were taken during Bunsen's life. But in recent years solutions have been widely studied, under rather limited conditions of temperature and pressure, to be sure, but it has resulted in establishing relations—like the *phase rule*—of such effective and far-reaching character, that now, just half a century afterward, we are entering with great vigor upon the prosecution of Bunsen's suggestion. It is now possible to establish definite limits of solubility of one mineral in another, and definite conditions of equilibrium, even in rather complicated groups of minerals, which enables us not only to interpret the relations developed by such a thermal study as that outlined above, but also to assure ourselves that only a definitely limited number of compounds of two minerals can exist, that they must bear a constant and characteristic relation to each other under given conditions of temperature and pressure, and that changes of temperature and pressure will affect this relation in a definite and determinable way. Physical chemistry not only takes into account the chemical composition of mineral compounds, but their physical properties as well, thruout the entire temperature region in which they have a stable existence, and therefore furnishes us at once with the possibility of a new and adequately comprehensive classification of all the minerals and rocks in the earth. The value of an adequate system of classification appeals chiefly to those whose duties bring them into intimate relations with the subject matter of a science, but so much may appropriately be said, that a consistent application of physical chemistry to the minerals may

operate in the not far distant future to develop an entirely new conception of the science of mineralogy.

As the number and scope of such exact measurements increase, we gradually build up what may be called a geologic thermometer. Just as the location of fossils offers a basis for estimating geologic time, it often happens that a mineral takes on a variety of different crystal habits, according as it happened to form at one temperature or another. Quartz, for example, which is one of the commonest of natural minerals and one of the most familiar, undergoes two changes in its crystal form which leave an ineffaceable record. One occurs at 575° and the other at 800°. An optical examination of even a minute quartz fragment from the mountainside will reveal to the skilful petrologist whether the crystal formed at a temperature below 575°, between 575° and 800°, or above 800°. And if we could have at our disposal a great body of such exact measurements of the temperature region within which particular crystals originate and remain stable, we could apply that directly to terrestrial formations in which this mineral occurs, and read therein the temperature which must have obtained during their formation. All this will not be done in the first year, and perhaps not in the first decade; but the ultimate effectiveness of this method of procedure in establishing the relations between the minerals and the valuable ores is now as certain of success as the operations of any of the sciences which have now come to be characterized as exact, as opposed to descriptive.

There is one important difference between the great laboratory of nature and its feeble human counterpart. Nature operated with large masses, mixed with a generous hand, and there was always plenty of time for the growth of great individual crystals, at which we marvel whenever we encounter them, and which we have sometimes come to regard highly as precious stones. To carry these processes into the laboratory is necessarily fraught with certain limitations. The quantities must remain small and the time and available financial resources will always be limited. So long as we are able to ascertain the optical character of a crystal with equal exactness whether the crystal is of the size of the

proverbial mustard-seed or a walnut, the scientific laboratory cannot properly afford the time necessary to produce the large crystals which nature offers so abundantly. Furthermore, the crystals of nature often owe their brilliant coloring to slight admixtures of impurity, which, to the scientific laboratory, spell failure and are avoided with the utmost care. Most of the mineral crystals, when reproduced in the laboratory, are quite colorless. And so, altho the question is often raised whether we are not really engaged in the artificial production of gems, and altho the seductive character of such an investigation would no doubt appeal to many, it must be admitted that the geological laboratory is not and probably will never become the serious competitor of nature in those directions in which nature has produced her most brilliant effects.

In what has preceded, I have laid emphasis upon the value of experimental measurements in the systematic development of a more exact science of the earth. It is a fair question, and one which is very often raised, whether all this investigation has a utilitarian side, whether the knowledge obtained in this way and with such difficulty, will help to solve any of the problems arising in the exploitation of our mineral resources or assist in our industrial development. It is neither wise nor expedient, in entering upon a new field of research, to expatiate long upon its practical utility. Its principles must first be established, after which there is no lack of ingenuity in finding profitable application of them.

The development of thermoelectric apparatus for the accurate measurement of high temperatures was begun and has been perfected in the interest of geophysical research, and it has already found such extended application among the technical industries as to demand the manufacture and calibration of thousands of such high temperature thermometers every year. The tempering and impregnation of steel are no longer dependent upon the more or less trained eye of the workman, but are done at measured temperatures and under known conditions which guarantee the uniformity of the product and admit of adaptation to particular purposes, like high speed tools or armor plate. This has the incidental but far-reaching industrial consequence that workmen

of great individual skill in these industries are much less necessary now than formerly. Everything is accomplished by bringing temperature conditions under mechanical control and making them absolutely reproducible without the exercise of critical judgment on the part of anyone.

A more intimate knowledge of the behavior of the minerals themselves finds almost immediate industrial application. An industry which has grown to enormous proportions in recent years is the manufacture of portland cement, about which little more has been known than that if certain natural minerals were taken in the proper proportions and heated in a peculiar furnace developed by experience, the resulting product could be mixed with water to form an artificial stone which has found extensive application in the building trades. Chemical analysis readily established the fact that the chief ingredients in a successful portland cement were lime, alumina and silica, with a small admixture, perhaps, of iron and magnesia; but the relation in which these ingredients stood one to another,—that is, which of them were necessary and which merely incidental,—and in what compounds and what proportions the necessary ingredients required to be present, has never been satisfactorly established. When we know the stable compounds which lime, alumina and silica can combine to form, together with the conditions of equilibrium between these for different temperatures and percentages of each component, a formula can be written offhand for a successful portland cement from given ingredients somewhat as an experienced cook might write out the recipe for a successful dish. Such definite and valuable knowledge is not beyond our reach. To obtain it requires, in fact, precisely the same system of procedure which has been described above and which has already been successfully applied to many of the natural minerals which have been reproduced and studied in the Geophysical Laboratory during the past five years. It happens that we have examined a considerable number of these very mixtures in our recent work upon the rocks. All the compounds of lime, silica and alumina have been established, and a portion of the silica-magnesia series, and their relations have been definitely determined thruout the

entire range of accessible temperatures. There is no reason to apprehend serious difficulty in applying the same procedure to the commercial ingredients of portland cement, and replacing the present rule-of-thumb methods and uncertain products with dependable cements. The problem of determining the relation of the ingredients in commercial cement and the conditions necessary for its successful formation is exactly the same in character as that of determining the conditions of formation of the rocks of the earth.

A physico-chemical investigation of the sulphide ores over a wide range of temperatures and pressures has also been undertaken, which has developed a large body of exact information of value in mining industry. And such illustrations could be continued almost indefinitely, if it would serve any useful purpose to do so.

The industrial world is not as a rule interested in scientific principles; the principle must first be narrowed down to the scope of the industrial requirement before its usefulness is apparent. The immediate effect of an industrial standpoint is therefore to restrict investigation at the risk of losing sight of underlying principles entirely. An illustration of this has come down to us thru the pages of history, of a character to command and receive the utmost respect, for such another can hardly be expected to occur. We have honored the early philosophers for their splendid search after broad knowledge; but in what is now the field of chemistry, they allowed themselves to be turned aside to the pursuit of a single, strictly utilitarian problem,—the transmutation of base metals into gold. The history of chemistry is a history of this one problem from the fourth to the sixteenth century,—twelve centuries before a man arose whose broader standpoint enabled him to divert the fruitless search into other channels from which a science has slowly arisen which is now so broad as to overlap most of the other sciences, and withal so practical that hardly an industry is entirely independent of it.

The so-called practical questions may therefore as well be left to take care of themselves. There has been no lack of ingenuity in making profitable application of systematic knowledge when-

ever the need for it became insistent, for the rewards of such effort are considerable. And it is no longer an argument against proceeding to establish relationships in a new field, that the scope of their application cannot be completely foreseen.

Now, what more promising questions occur to one than these: If the earth was originally fluid, as it appears to have been, and has gradually cooled down to its present state, its component minerals must at some time have been much more thoroly mixed than now; how did they come to separate in the process of cooling into highly individualized masses and groups as we now find them, and what were the steps in their deposition? If the whole earth was hot, whence came the marble of which we have so much and which can withstand no heat? What has given us the valuable deposits of iron, of gold, of precious stones? What determines the various crystal forms found in the different minerals, and what is their relation? Some must have formed under pressure, some without pressure, some with the help of water, and some without. Where is the center, and what the source of energy in our volcanoes? All these questions, and many more, the geophysicist may attempt to answer.

PHYSICS.—*A correlation of the elastic behavior of metals with certain of their physical constants.* JOHN JOHNSTON. Communicated by A. L. Day.

As is well known, the effect of pressure acting on both the solid and liquid phase of a single substance is to raise or lower its melting point according as the process of melting is accompanied by an increase or a decrease of volume respectively, the latter being the exceptional case. But, when pressure acts only on the solid phase, but not—or not to the same extent—on the liquid phase, the melting point is always lowered and by an amount which is many times as great as the corresponding change produced by the same pressure acting on both the liquid and the solid phase.

It seemed of interest to calculate the effect of pressure, acting on the solid phase alone, in lowering the melting point of metals, and to compute the amount of such unequal pressure required

to cause the metal to melt at, or about, 25°. The method of calculation follows.

The application of thermodynamical principles to this case yields the differential equation.[1]

$$\frac{dT}{dP} = \frac{T_1}{QD} \quad \text{.....(I)}$$

which when integrated so as to be applicable to the case in hand becomes

$$\frac{\Delta T_1}{\Delta P} = \frac{T_1}{42.72 Q_1 D_1} \quad \text{.....(II)}$$

according to which the change in melting-point (ΔT_1) produced by a pressure (ΔP) acting only on the solid phase is expressed in terms of the melting point (T_1) at atmospheric pressure, the heat of melting (Q_1), and the density (D_1) of the solid at ordinary temperature and pressure.

Lack of space precludes a discussion, and justification, of the assumptions involved in obtaining this integrated form of equation I; suffice it to say that the matter has been carefully considered, and that any inaccuracy in this integration is quite unimportant in the present connection, more especially since the accuracy of the available values of Q_1 (and even of D_1) leaves much to be desired.

The above formula has been applied to the calculation of the lowering of melting point produced by 1 atmosphere excess pressure on the solid in the case of all the metals[2] for which values of

[1] A succinct mode of deriving this equation is given by G. N. Lewis (J. Am. Chem. Soc., **30**: 680. 1908).

[2] Excepting iron, on account of the uncertainty of what "iron" is, and the disparity of the recorded values. The value given for nickel in Landolt-Börnstein-Meyerhoffer Tabellen (p. 470) as a heat of fusion (taken from Pionchon, Ann. chim. Phys., (6), **11**: 106. 1887) was found, on reference to the original, to be a heat of *transformation* (occurring somewhere between 230° and 400°); consequently nickel could not be included. (Similarly, Pionchon's values for iron given in L.-B.-M. (p. 470) are heats of *transformation*.) Mercury and gallium are omitted, since they are liquid at ordinary temperatures. The value of Q, for aluminium is somewhat doubtful: it was calculated from the "total heat" (as given in L.-B.-M.) by means of the specific heat of aluminium (0.30) as given by Bontschew (L.-B.-M., p. 383). No alloys could be included, owing to lack of the necessary data; in any case the formula is applicable only to those alloys which melt at a definite temperature.

Q_1 are given in Landolt-Börnstein-Meyerhoffer Tabellen (2 Aufl. p. 470). For some metals more than one value is given, but it is at present impracticable to determine which are most reliable; for this reason, the mean value was adopted in all such cases. For the same reason, the general mean value of the density, as given in the tables (pp. 224–9) was taken. The melting points are those now generally adopted. The data and results are brought together in Table 1.

TABLE 1

LOWERING OF MELTING POINT OF METALS EFFECTED BY UNEQUAL PRESSURE

METAL	MELTING POINT		HEAT OF FUSION	DENSITY		
	t	T_1	Q_1	D_1	ΔT_1	φ_{25}
K	62	335	15.7	0.87	0.574	64
Na	97	370	31.7	0.98	0.279	260
Pb	327	600	5.4	11.37	0.229	1320
Sn	232	505	14.1	7.29	0.115	1800
Bi	270	543	12.5	9.80	0.104	2360
Cd	321	594	13.7	8.64	0.117	2520
Al	658	931	42.	2.60	0.200	3170
Zn	419	692	28.	7.1	0.081	4840
Ag	960	1233	23.	10.50	0.120	7820
Cu	1083	1356	43.	8.93	0.083	12800
Pd	1550	1823	36.3	11.4	0.103	14800
Pt	1755	2028	27.2	21.5	0.081	21300

The last column of Table 1 contains the values (in atmospheres) of the excess pressure (acting on the solid only) required to cause the metal to melt at 25°; these were calculated from the expression

$$\varphi_{25} = (T_1 - 298) / \Delta T_1 \quad \text{(III)}$$

The metals are arranged in the order of increasing values of φ calculated in this way. It was conjectured that this order might bear some relation to that obtained when these metals are arranged with reference to the relative values of their elastic constants and mechanical properties.

The most obvious mechanical property with which to compare the series of φ values is the flow-pressure. This was deter-

mined by Tammann, Verigin and Levkojeff[3] for a series of metals. Arranged in the order of decreasing ease of flow, the metals follow in the order K, Na, Pb, Tl, Sn, Bi, Cd, Zn, Sb, a sequence which is identical with that deduced thermodynamically and presented in Table 1. But not only is the sequence of φ values identical with that of the flow pressure, it is practically identical with the sequence obtained when the metals are arranged in the order of *any* of their elastic properties for which measurements have been made. This is shown by Table 2, in which have been brought

TABLE 2

RELATIVE VALUES[4] OF THE ELASTIC CONSTANTS OF METALS

METALS IN ORDER AS IN TABLE 1	COMPRESSIBILITY	HARDNESS	TENSILE STRENGTH		ELASTIC LIMIT			ELASTIC (YOUNG'S) MODULUS	RIGIDITY MODULUS	
						Lower	Upper			
	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)		(*g*)	(*h*)	(*i*)
K	31.5	0.5								
Na	15.4	0.4								
Pb	2.2	1.5	2.0	21	0.3	25	102	17	5	0.80
Sn	1.7	1.8	2.1	36	4	34	55	34	16	1.50
Bi	2.8	2.5						32	12	
Cd	1.9	2.0		48		28	109	71	17	2.31
Al	1.3	2.9				283	600	70	29	2.55
Zn	1.5	2.5	13		10	125	770	78	31	
Ag	0.84	2.7	22	272	12			70	39	2.67
Cu	0.54	3.0	25	316	12	203	2780	108	42	4.37
Pd	0.38	4.8			27			103	46	
Pt	0.21	4.3	29		26			161	52	6.46

(*a*) As given by Richards and collaborators, J. Am. Chem. Soc., **31**: 156. 1909.
(*b*) According to Rydberg, L.-B.-M. Tabellen, p. 57.
(*c*) L.-B.-M. Tabellen, p. 53.
(*d*) Wertheim (1848) quoted by Faust and Tammann, Z. Physik. Chem. **75**: 118. 1911.
(*e*) L.-B.-M. Tabellen, p. 53.
(*f*) As determined by Faust and Tammann, loc. cit.
(*g*)·(*h*) General mean of the (sometimes very discordant) values given in. L.-B.-M. Tabellen, pp. 43–45.
(*i*) Horton, Phil. Trans. Roy. Soc. London, A, 204. 1905.

[3] Ann. Physik, **10**: 649. 1903.

[4] It is to be noted that the values given in the table are *relative* only, and are not always expressed in the same units (e g., columns *c* and *d*, *e* and *f*, *h* and *i*).

together all the data available on the elastic properties, namely, compressibility, hardness, tensile strength, elastic limit, elastic modulus, and modulus of rigidity.

From this table it is evident that as the value of φ increases, the compressibility decreases, and the values of the other elastic properties increase steadily. The exceptions to this statement are very few as regards any one property, and vary irregularly as we pass from one property to another; in other words, there are no systematic divergences between the sequence of the metals as derived from the thermodynamic relationship discussed in this paper, and that obtained when they are arranged progressively with reference to any one of their elastic properties. The slight divergences are no greater than one might expect from the uncertain character of the thermal data, on the one hand, and of the elastic constants on the other.

From the above, then, it appears to be true that the mechanical properties of metals are correlated with the amount of pressure—assumed to act on the solid alone—requisite to cause the metal to melt at or near the ordinary temperature. This pressure in turn depends upon the melting point, the density, and the heat of melting, of the metal. The first two of these quantities are known to be periodic functions of the atomic weight, and there is every reason to believe that the heat of melting, and therefore also φ, is. Therefore we should expect some, or all, of the elastic properties to be periodic functions. So far, thoro measurements have been made only on the compressibility, which, according to Richards, shows marked periodicity.

The remarkable concordance shown in the above table, which can hardly be due to coincidence, indicates that the "flow" of metals—or indeed, every permanent distortion of a crystalline solid—is due to an actual fusion and resolidification of the crystals.

These considerations may also be used to throw light on the general behavior and properties of metals, and on many geological phenomena; but it would lead too far to go fully into these matters. We wish, however, to give briefly a mechanical picture of the probable mode of action of unequal pressure upon a metal, and to indicate how such an explanation accounts plausibly for many

of the phenomena observed in the "hardening" of metals, and for the increase of strength following upon deformation.

Le Chatelier[5] used this conception of unequal pressure to account for regelation—the consolidation of a mass of loose snow at 0° into a block of solid ice. The pressure, due to the superincumbent material, lowers the melting point at the surface of contact of adjacent grains by an amount Δt. The water formed flows out into the interstices of the snow grains, where it is at a pressure of 1 atmosphere but at a temperature of $-\Delta t$, and is in contact with ice at 0°; consequently it freezes again. This process continues until all the interstices are filled up; that is, until a solid block of ice is formed. The behavior of metals under the action of an unequal compression we conceive to be identical with that pictured above for ice. Namely, that metal melts wherever the pressure reaches the appropriate value, flows into the interstices where the pressure is smaller, and solidifies again, with the formation in general of very small crystals, owing to the exceedingly rapid rate of recrystallization.

This mode of action, besides accounting in an approximately quantitative manner for many of the phenomena observed with metals, is also in harmony with observations on the structure of metal which has "flowed" or has been subjected to deformation of any kind.

According to Beilby[6] the process of deformation is always accompanied by a partial transformation of the metal to an "amorphous" form, which acts as a cementing material for the untransformed grains. In favor of this view, he adduces evidence that there is (*a*) a difference in the energy content of the strained and unstrained metal, which is manifested in a difference between the two forms, (1) in their electrolytic potential when immersed in a solution, (2) in their thermo-electric power, (3) in their heat of solution; (*b*) a difference in structure manifested in differences in (1) microscopic appearance, (2) mechanical properties,—hardness, tensile strength, etc., (3) density, (4)

[5] Z. physik. Chem., 9: 338. 1892.
[6] Phil. Mag. (6), 8: 258–76. 1904.

conductivity for heat or electricity, etc. According to Faust and Tammann,[7] on the other hand, the change of properties on deformation is parallel to the formation of smaller crystallites.

Whichever be the correct interpretation—if indeed these views are mutually exclusive—the fact remains that changes in the properties of a metal ensue upon deformation, the most important one from a practical standpoint being an increase in its rigidity. The considerations presented in this paper are not inconsistent with either of the above views, and in addition, account easily for the increased rigidity of metal which has been strained. For, exactly as in the case of the consolidation of loose snow to a block of ice, as soon as the stress reaches an appropriate value (the lower elastic limit), melting and flow into the interstitial spaces take place, with immediately subsequent recrystallization; this process continues until flow is no longer possible (the upper elastic limit), whereupon increased stress produces a rupture of the material. Now, the actual process of flow diminishes the volume of the spaces into which flow is possible, and to this extent diminishes the inequality of pressure acting on liquid and solid; hence it requires progressively higher pressures absolutely (though at the same temperature the same *excess* of pressure on the solid) to produce flow; in other words, the rigidity of the material is increased.

Moreover, it is a well-known fact that the strength of eutectics (which are always fine-grained) is always greater than that of their components; further, that the varieties of steel possessing the greatest tensile strength (e.g., vanadium steels) are very fine-grained. From the standpoint of this paper, such metals are strong *because* they are fine-grained, and hence, if we wish to make a steel of high tensile strength, we should endeavor to obtain a very fine-grained structure, producing this by whatever means (addition of foreign material, heat-treatment, or mechanical treatment) may be found suitable for this purpose.

Summary. The object of this preliminary note is to establish the existence of a parallelism between the elastic properties of

[7] Z. physik. Chem., 75: 108–26. 1911.

metals and an expression—involving certain of their physical constants only—derived from thermodynamical principles on a basis which is equivalent to the assumption that the "flow," or permanent distortion, of a metal is a manifestation of an actual *melting* produced by a stress (pressure) acting on the solid phase, but not—or not to the same extent—on the liquid phase. Some of the implications of this theory are discussed briefly.

BOTANY.—*A new Echeveria from Mexico.* J. N. Rose.

The botanical collections of the National Museum have all been greatly increased during the last few years but especially in those groups to which intensive study has been given, like the ferns, succulents, and Laciniaria. In no other group has this growth been so marked either in number of specimens or of new species as in the Crassulaceae of Mexico. In the case of these plants exhaustive and definitely directed field work has been carried on for fifteen years, while the maintenance of a large living collection has furnished good material for full and accurate diagnoses and for the making of good herbarium specimens of most of the species.

In 1880 the Crassulaceae of Mexico were catalogued by Mr. W. Botting Hemsley, who recognized 4 genera and 62 species. When the writer began his work on the group the National Herbarium contained representatives of all these genera and about 54 of the species, amounting to 86 sheets or specimens.

In 1905 Britton and Rose revised this family for the North American Flora. They recognized 17 genera and 164 species from Mexico. Since then 32 species have been described, making the total known from Mexico 196.

All these genera are represented in the collections of the National Herbarium and all the species with the exception of 8 or 10 of the older and obscure ones. The number of sheets has arisen to a total of 847. In spite of the long-continued study of this group new species are constantly coming to light, of which the following is one.

Echeveria lutea Rose, sp. nov.

Basal leaves numerous, ascending, thickish, 8 to 10 cm. long, light green, glabrous with upturned margins forming a deep trough, acuminate with mucronate tip, the apical portion upturned like a horn; flowering stem 20 to 30 cm. long; leaves 4 to 5 cm. long, linear, semiterete, stiff, flattened on the upper surface, pointed, with a toothed free margin at base; inflorescence a secund raceme, at first strongly reflexed but at the flowers often becoming erect; flowers 20 or more, often subsessile; sepals 5, distinct, very unequal, the longest 2 cm. long, free and toothed at base, linear, pointed, ascending; flower bud strongly 5-angled and pointed; corolla lemon yellow, 15 mm. long, the lobes distinct for about two-thirds their length but not spreading except a little at the tip.

Type in U.S. National Herbarium, no. 619743, collected at San Rafael, San Luis Potosi, Mexico, November, 1910, by C. A. Purpus and flowered in Washington, July, 1911.

This is a very remarkable species and quite distinct from all the others which we have had in cultivation. The foliage is of a rather pale green color, quite stiff, almost pungent. The flowers are a lemon yellow, an unusual color in the genus, only one other species being at all like it.

FIG. 1. *Echeveria lutea* Rose, sp. nov.

ABSTRACTS

Authors of scientific papers are requested to see that abstracts, preferably prepared and signed by themselves, are forwarded promptly to the editors. Each of the scientific bureaus in Washington has a representative authorized to forward such material to this journal and abstracts of official publications should be transmitted through the representative of the bureau in which they originate. The abstracts should conform in length and general style to those appearing in this issue.

PHYSICS.—*The reflecting power of various metals.* W. W. COBLENTZ. Bulletin Bureau of Standards, Reprint 152. 1911.

The reflectivity of various substances is given including tungsten, tantalum, molybdenum, chromium, antimony, tellurium, vanadium, silicon, graphite, etc. The paper gives also (Note I) the thermoelectric properties of molybdenum, (Note II) a method for the preservation of silver mirrors, and (Note III) comments on radiation laws of metals (see also Bull. Bur. Standards, Reprints 45 and 105). W. W. C.

GEOLOGY.—*Mineral resources of the Llano-Burnet region, Texas, with an account of the pre-Cambrian geology.* SIDNEY PAIGE. Bulletin U. S. Geological Survey No. 450. Pp. 103, with maps, sections, and views. 1911.

The rocks of the region are: (1) pre-Cambrian schists, gneisses, and granites, (2) Paleozoic sandstones, limestone, and shales, and (3) Cretaceous sandstones, clays, and limestones.

The folded and faulted Paleozoic strata, which surround the pre-Cambrian area, are separated from the pre-Cambrian by a great unconformity. The Cretaceous formations rest almost undisturbed with pronounced unconformity on the Paleozoic rocks.

The pre-Cambrian (Algonkian?) rocks have been divided into (1) the Packsaddle schist, predominantly basic, including amphibolite and mica schists and old basic intrusive rocks; (2) the Valley Spring gneiss, including quartzites or their derivatives, light-colored mica schists, and acidic gneisses; (3) a very coarse-grained pink granite; (4) all other granitic rocks.

The granite cuts the schist as batholiths, dikes, and sills, and, in pegmatitic phase is found in minute veinlets and in huge dikes and sheets. There are all gradations between granite and schist.

In some localities the contacts between schists and dikes are sharp; at others the temperature of the intruding mass was so high that

masses of schist melted; and elsewhere granitic material forced itself between the layers of the schists and formed injection gneisses.

The iron ores are chiefly magnetite or mixtures of magnetite with hematite. The magnetite deposits typically conform with the layering of the enclosing schistose rocks, notably in the case of the leaner ore bodies.

The geologic history of the Llano ores is as follows: (1) Deposition of iron as oxide, carbonate, etc., with the sediments, either in extended basins or along borders of the sea; (2) Burial, followed by intrusion of dikes and sills of a diabasic type with possible local introduction of soda and perhaps granitic intrusions; (3) Deeper burial with subsequent folding and metamorphism and a second intrusion of basic types; (4) Intrusion by granite with great local disruption; (5) Elevation and erosion. H. D. McCaskey.

ECONOMIC GEOLOGY.—*Copper deposits of the Appalachian States.* Walter Harvey Weed. Bulletin U. S. Geological Survey No. 455. Pp. 166, with 5 plates and 32 sections. 1911.

Throughout the Appalachian province the copper ores are confined to (1) crystalline schists; (2) altered basalts; (3) Triassic rocks close to trap intrusions; and (4) Devonian rocks, in which they are generally insignificant. No two deposits are precisely alike, yet if their general characteristics be considered they all fall into six types, as follows:

(1) Ducktown type. Pyrite lenses and veins in crystalline schists. (2) Copper quartz-vein type. Quartz veins containing metallic sulphides: (a) Virgilina variety; quartz veins with glance and bornite. (b) Gold Hill variety; silicified schists, containing chalcopyrite and pyrite, with ore shoots of quartz and chalcopyrite. (c) Seminole variety; zone of pyritized schists, carrying local shoots of high-grade ores. (3) Carolinian type. Bands of amphibolite traversing mica schists and carrying chalcopyrite and pyrite disseminated through the rock or gathered in bunches or, more commonly, deposited in the gray gneiss alongside. (4) New Jersey type. Impregnated shale and sandstone adjacent to trap masses; in part in the trap. (5) Pahaquarry type. Devonian sandstones impregnated with copper ores; and shales, etc., of Coal Measure regions with occasional ore; not rare, but insignificant in amount. (6) Blue Ridge (Catoctin) type. Bunches and joint fillings in the surficial portions of the basaltic rocks (Catoctin schist) of the Blue Ridge region. F. L. Ransome.

ENTOMOLOGY.—*Descriptions of new species of wasps with notes on described species.* S. A. ROHWER. Proceedings U. S. National Museum, **40**: 551–587. 1911.

Forty-five new species and five new sub-species or varieties. One new genus, *Gonostigmus*, is described, and the type species is indicated for several other genera. Much of the material came from the Western States or Central America. N. BANKS.

ENTOMOLOGY. *Descriptions of six new genera and thirty-one new species of Ichneumon flies.* H. L. VIERECK. Proceedings U. S. National Museum, **40**: 173–196. 1911.

Most of the new species are from the United States, but several are from Portuguese East Africa, a few from South America, Japan, and the Hawaiian Islands.

New generic names are *Cryptoxilos*, near *Peristenus; Dolichozele*, near *Zele; Platyspathius* near *Spathius, Polystenidea* near *Hecabolus*, and *Stenopleura* near *Protapanteles*. New subgeneric names are *Dolichogenidea*, subgenus of *Apanteles;* and *Daiotes* and *Mastrus, subgenera* of *Phygadeuon;* these last two are stated to be "genera" but only used in a subgeneric sense. One or two more of Foester's names are perhaps, for the first time, connected with species. N. BANKS.

ENTOMOLOGY.—*New species of reared Ichneumon flies.* H. L. VIERECK. Proceedings U. S. National Museum, **39**: 401–408. 1911.

Descriptions of eleven new species are given and, apparently, no new generic names; nearly all were bred from insects of economic value. N. BANKS.

ENTOMOLOGY.—*Descriptions of one new genus and eight new species of Ichneumon flies.* H. L. VIERECK. Proceedings U. S. National Museum, **40**: 475–480. 1911.

The new generic name, *Cyanopteridea*, is for Cyanopterus Szepligeti (not Haliday). *Parapahteles* Ashm. is made a synonym of *Apanteles*. Several of the species have been bred in connection with the work on the Gipsy moth. N. BANKS.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

THE BOTANICAL SOCIETY OF WASHINGTON

The eleventh annual meeting of the Botanical Society of Washington was held in the Bureau of Chemistry building Tuesday, October 24, 1911, President W. J. Spillman presiding.

The reports of the Secretary, Treasurer, and the Executive Committee showed that the Society is in a flourishing condition. Eight program meetings were held during the year with an average attendance of thirty-nine. Nineteen new members were added during the season, while five were lost by reason of removal from Washington and vicinity.

Officers as follows were elected for the ensuing year:

President, W. A. Orton; Vice-President, A. S. Hitchcock; Recording Secretary, Edw. C. Johnson; Corresponding Secretary, W. W. Stockberger; Treasurer, F. L. Lewton; Vice-President in the Academy of Sciences, W. R. Maxon.

At the 74th meeting of the society, at the Cosmos Club, October 10, 1911, at 8 P. M., the following papers were read: *The wilting coefficient for different plants and its indirect determination.* L. J. Briggs and H. L. Shantz. (See this Journal **1**: 228. 1911.) *The forest of Arden, a dream.* H. C. Skeels.

Edw. C. Johnson, *Secretary, pro tempore.*

PROGRAMS AND ANNOUNCEMENTS

WASHINGTON SOCIETY OF ENGINEERS

December 5, 8 P. M. C. & P. Telephone Company's Hall. Discussion of Oyster Fisheries, in which Dr. H. F. Moore, Bureau of Fisheries, Dr. Caswell Grave, Scientific Member of the Maryland Shellfish Commission, and Mr. C. C. Yates, of the Coast and Geodetic Survey, will participate.

December 19, 8 P. M. Cosmos Club Hall. Annual meeting and election of officers. Mr. George W. Littlehales will give a paper on the relation of the engineer to the advance of civilization.

PHILOSOPHICAL SOCIETY

701st Meeting and 41st Annual Meeting. December 9, 1911. Cosmos Club at 8.15. Reports and election of officers.